CHAPTER 4. ENGINEERING ANALYSIS

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CHAPTER 4. ENGINEERING ANALYSIS

This chapter provides the technical support documentation for the engineering analysis of high-intensity discharge (HID) lamps. For this determination, the engineering analysis identifies representative equipment categories with baseline lamps and energy-efficient substitutes and develops power rating estimates for the equipment analyzed. The outputs from the engineering analysis are critical inputs to subsequent cost-benefit calculations for individual consumers.

In this determination, the U.S. Department of Energy (DOE) developed end-user prices for analyzed lamp, lamp-and-ballast, and luminaire (fixture) designs using a commercially available pricing database. By combining the results of the engineering analysis and the equipment price analysis, DOE derived the necessary inputs for use in the life-cycle cost (LCC) analysis and national energy savings/net present value (NES/NPV) analysis. The LCC and NES/NPV analyses are discussed in chapters 5 and 6, respectively, of this technical support document.

4.1 ENGINEERING ANALYSIS FRAMEWORK

DOE based the engineering analysis on commercially available equipment that incorporates the design options identified in the market assessment (chapter 2) and technology assessment (chapter 3). For this determination, DOE used the following approach for the engineering analysis:

1. *Representative Equipment Categories.* DOE reviewed potentially covered lamps and selected certain broad categories as "representative" based on their market share, wattage, and color characteristics.

2. *Baseline Lamps.* Within the broad equipment categories, DOE selected baseline lamps as representative equipment. Generally, a baseline lamp is one that represents the typical lamp sold. DOE selected specific characteristics such as certain color rendering index, operating lifetimes, and light outputs to characterize the lamps that are most commonly purchased by consumers. DOE selected multiple baseline lamps to ensure consideration of different high-volume lamps and their associated consumer economics.

3. *Substitute Lamps.* DOE selected more efficacious substitute lamps for each baseline lamp in the representative equipment classes. In identifying more efficacious lamp designs, DOE recognizes that a lamp's lumen package and performance characteristics are important design criteria for consumers. For example, if consumers do not have the option to purchase substitute lamps, lamp-and-ballast systems, or luminaires with similar lumen packages under an energy conservation standard, consumers would need to change the lighting design to maintain a similar light output. Therefore, DOE established energy-efficient designs for the LCC analysis so that potential light output is equal to or within 90 percent (or greater) of the mean light output of the baseline system.

The sections that follow discuss how DOE applied this methodology to create the engineering analysis.

4.1.1 Representative Equipment Categories

For this determination, DOE developed equipment categories that represent the plurality of total HID lamp shipments in the United States. The equipment is categorized broadly by lamp wattage and baseline lamp technology. HID lamp wattages were segregated into three categories: low (less than 150 watts [W]), medium (from 150 to 500 W), and high (greater than 500 W). Based on its market assessment, DOE selected medium wattage categories as most representative of lamp shipments, comprising an estimated 38 percent of total HID lamp shipments in the United States.

DOE further specified the equipment categories by lamp technology—in this case, mercury vapor (MV) and probe-start metal halide (MH) lamps—which broadly characterizes the color requirements of HID lamp applications. For the MV baseline equipment classes, DOE assumed that color appearance and color rendering are not critical (*e.g.*, roadway lighting and industrial applications), which allows for energy-efficient substitute lamp types with poor or moderate color rendering (*e.g.*, high-pressure sodium [HPS] and probe-start MH). DOE selected probe-start MH as the baseline lamp technology for equipment classes where color appearance and color rendering may be important (*e.g.*, interior and exterior "white light" applications in commercial facilities).

4.1.2 Baseline Lamps

Within the broad wattage and lamp technology categories, DOE created multiple equipment categories to capture high-volume equipment and the equipment's associated economic impacts. The equipment categories are identified by a nominal initial light output and an associated baseline lamp (MV or probe-start MH), and are presented in section 4.1.3.

In this determination, DOE based its equipment categories on lamps. This is because the potential energy conservation standards would apply only to lamps. However, DOE used a systems approach in analyzing the representative equipment categories because both lamps and ballasts determine a system's energy use and light output. Accordingly, DOE paired lamps with ballasts to develop representative lamp-and-ballast systems, which demonstrate the actual energy usage and light output of operating lamps. DOE only considered magnetic ballasts for this analysis. Although electronic ballasts exist for some HID lamps, these types of ballasts represent a very small segment of the market.

4.1.3 Substitute Lamps

For each representative equipment category, DOE considered the following when identifying acceptable substitute HID lamps:

- *Light Output*: Some substitutions are not suitable because of light output differences. Substitute lamps with significantly increased light output may not be appropriate, despite their higher efficacy. Higher light output for a system in an existing luminaire may cause glare, which may be a safety hazard or create lighting quality issues, or both. In this determination, DOE analyzed lamp-and-ballast systems that both save energy and maintain comparable light output. In particular, DOE considered lamp-and-ballast

designs that emit mean lumens equal to or within 90 percent (or greater) of the mean light output of the baseline system. DOE maintains light output across efficacy levels to ensure that products supply comparable service.

In assessing light output, DOE makes a distinction between mean and initial lumens. DOE typically uses initial lumens in its test procedures to measure compliance with a standard. This is consistent with consensus industry standards for efficacy measurements. However, the light output of a lamp decreases over time. To account for this real-world depreciation in lumens, DOE used mean lumens in determining equivalent substitutes in the LCC and NES/NPV analyses.

- *Color Characteristics*: Some substitutions are not suitable because of color (*i.e.*, spectral) differences, which may exclude some technology options for specific applications. For example, an HPS system (with its characteristic amber color appearance and poor color rendering) would not be an appropriate substitute for an MH system in color-critical "white light" applications (*e.g.*, an interior lobby). However, HPS can be a viable substitute for MH in some exterior applications (*e.g.*, parking structures), where energy efficiency may be a higher priority than color quality.

- *Luminaire Constraints*: Some substitutions are not suitable because of luminaire constraints. A substitution of a different HID technology type may mean the use of a lamp with a different socket type (*e.g.*, mogul, medium, pin) that does not exist in the luminaire. Replacement lamp options and their ballasts may not fit in the existing luminaire. Some HID luminaires are not enclosed and cannot protect against lamp rupture for some technology replacements.

- *Economics*: Lighting economics could significantly affect the choice of a substitution. Lamps that provide acceptable light output and/or color quality can have a high initial cost, making their LCC too high to be a reasonable substitute. Material and maintenance costs associated with shorter life and increased lamp replacements can also adversely affect the LCC of the substitute product.

4.2 EQUIPMENT PRICE DETERMINATION

For substitutions requiring luminaire replacement, it is important to note that manufacturers typically package luminaires without a lamp; *i.e.*, they package and sell only the luminaire, which includes the housing, ballast, and other associated electrical and mechanical components (*e.g.*, wires, sockets, mounting brackets, fasteners). Therefore, to calculate the total price of a luminaire for the LCC analysis, DOE determined the price of associated lamps separately and added this to the luminaire price.

4.3 ENGINEERING ANALYSIS RESULTS

For this determination, DOE identified seven equipment classes of HID lamps that represent an estimated 38% of U.S. total HID lamp shipments. The analyzed baseline lamps and their energy-efficient substitutes fall in two broad wattage categories—low (less than 150 W) and medium (from 150 to 500 W)—and are classified by initial lumen output. The engineering

analysis also captures associated lamp-and-ballast input power ratings, light output, lamp life, and pricing information needed for the LCC and NES/NPV analyses. Error! Reference source not found. summarizes the engineering data for all baseline and substitute equipment.

Table 4.3.1. HID Lamps Determination Engineering Analysis Results

Wattage Category	Baseline Lamp Type	Equipment Class ID	Approx. Light Output *mean lumens*	Efficiency Level	Lamp Description	System Input Power Rating *W*
Medium Wattage (150–500W)	MV	1	6,800	Baseline	175W MV	202
				Substitute 1	150W PMH	185
				Substitute 2	100W HPS	122
		2	10,000	Baseline	250W MV	283
				Substitute 1	150W PMH	185
				Substitute 2	150W HPS	185
		3	14,400	Baseline	400W MV	454
				Substitute 1	250W PMH	285
				Substitute 2	150W HPS	185
	Probe-start MH	4	8,800	Baseline	175W MH	208
				Substitute 1	150W PMH	185
				Substitute 2	100W HPS	122
		5	13,700	Baseline	250W MH	291
				Substitute 1	175W PMH	209
				Substitute 2	150W HPS	185
		6	23,500	Baseline	360W MH	400
				Substitute 1	320W PMH	367
				Substitute 2	250W HPS	295
		7	25,200	Baseline	400W MH	456
				Substitute 1	320W PMH	367
				Substitute 2	250W HPS	295